Considerations for the design of mini-games integrating hints for puzzle solving ICT-related concepts

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Abstract—Educational games have been proved to be learning environments that are more in correspondence with new generation of students since they can provide successful learning and motivate students in their learning process. In this line, several studies describe the main factors that games should have in order to design engaging learning experiences. Taking into account these factors, this paper presents the design of three different game-based learning environments providing hints for puzzle solving different tasks within the area of computer architecture, programming fundamentals, and computing networks. An evaluation carried out with secondary and higher education students provides further considerations regarding the design of hints, score, and supportive learning material that should be taken into account when creating such kind of games.

Keywords—game-based learning; puzzle-based game; ICT engineering education

I. INTRODUCTION

According to Bourgonjon et al. [2], a large number of authors believe that new generation of students is fundamentally different from former generations, mostly because of changes in their media consumption patterns: students grow up with hypertexts, social networking programs and video games. These students have gained specific technical skills, new ways of thinking, and different learning preferences, which require a new educational approach [11]. In that sense, video games make learning meaningful and create a learning culture that is more in correspondence with the interests of these students [9]. In fact, computer games are often considered as embodiments of this new educational approach: games situate learning in meaningful contexts, empower students to become self-regulated; present students with ill-structured problems; integrate several knowledge domains; promote inquiry-based and discovery learning [2].

From the perspective of successful learning, motivation is an indispensable condition and games just happen to provide such a condition [12]. Besides, there is abundant empirical evidence supporting the positive effects of computer games as instructional tools, indicating that games strengthened and supported school achievement, cognitive abilities, motivation towards learning, and attention and concentration, and learners appear to be behaviourally active and self evaluating while playing games [1, 9]. However, in order to achieve these learning benefits, games have to be properly designed. In that sense, several studies have identified which factors to take in consideration for developing good educational games [3, 5, 10, 14]. Overall, these factors are mainly focused on highlighting the need of progressively increasing the difficulty level of the game, clearly defined the tasks and goals on the game, providing supportive learning material and appropriate feedback for the players action.

Taking these aspects in consideration, this paper explores both the factors and the educational principles to take in consideration in order to develop educational games, and describes three different games developed to teach specific concepts in the area of ICT engineering education. Experiments and findings from an evaluation of the different games with students from secondary education are also reported in the paper with the aim of providing more insights when designing such type of games. Main conclusions and further research lines derived from this work are also described in the paper.

II. DESIGN FACTORS IN DEVELOPING EDUCATIONAL GAMES

In order to design good educational games it is important to consider the main factors facilitating the achievement of expected learning outcomes. According to Coller & Scott [3], the learning principles embedded in good video games have a direct correspondence to constructivist theories of learning, active learning, and metacognition. Besides, in [14] several learning factors embedded in games have been identified: a) the goals of the game have to be clear; b) feedback has to be immediate, abundant, and unambiguous; c) the game has to progressively increase the level of challenge to keep players at the edge of their abilities; d) games should encourage active and critical learning, and knowledge and skills are discovered through direct experiences, in a cyclic process of probing, reflecting, hypothesizing, and testing; c) information has to be available to players at just the time they will be able to make sense of it and to use it. In line with this, Jones [5] proposes a set of characteristics on how to design engaging learning experiences: a) learners have to be able to complete and concentrate on the tasks; b) tasks should have clear goals, provide immediate feedback and deep but effortless involvement; c) games have to provide to the students a sense of control over their actions and self reflection after flow activity.
According to Kirriemuir & McFarlane [8], it might be worth to take into account some analyses that describe the pleasures of games play as a ‘flow’ experience instead of focusing on making learning fun to motivate students and the belief that learning by doing in games offers a powerful learning tool. Malone describes the following conditions to induce the flow state [10]: a) to structure the activity in such a way that the player can increase or decrease the level of challenges in order to match exactly personal skills with the requirements for action; b) to isolate the activity from other external or internal stimuli that might interfere with involvement in the activity; c) to develop a clear criteria for performance in order to allow a player evaluate their actions; d) to provide concrete feedback in the performance of the activities; e) the activity ought to have a broad range of challenges, and possibly several qualitatively different ranges of challenge, so that the player may obtain increasingly complex information about different aspects of her/himself.

On the other hand, taking in consideration that the problem with the design of most games is related to either the time required by learners interacting within games or to show improvement in achievement related to formal learning outcomes [6], a key point in game-based learning is to consider the design of appropriate help, feedback and hint structures to assist students in their learning experience [4]. Thus, we can group all the above-mentioned characteristics in the following factors for designing good educational games:

F1. Games should be based on constructivist learning theories, promote active learning and metacognition.
F2. Games have to clearly define the learning goals.
F3. Game has to be challenging and progressively increase the level of difficulty.
F4. Tasks have to be clearly identified within the game
F5. Immediate feedback has to be provided in regards with players’ actions.
F6. Supportive learning material has to be provided to players when performing a specific task.
F7. Help and hint structures should be provided to assist players within the learning process in the game to allow them complete correctly a specific task.

III. DESIGNING DIFFERENT ICT-DEVOTED MINI-GAMES

Taking in consideration the aforementioned factors, we have developed three mini-games within the areas of Information and Communication Technologies. Mini-games take 2 hours or less to complete or master that game, they have little complexity since they typically provide one single type of challenge, and mini-games are good for providing motivation to practice particular focused skills [13].

These mini-games are mainly characterized by puzzle solving the different tasks and providing different types of hinting to reach a correct solution. According to Kahn, puzzle games have shown pedagogical importance since puzzles leads a player step by step where the puzzle designer wants to go, and players have the feeling of control over the game [7]. Each designed game follows a problem-based approach (F1). In concrete, each level of the designed games is more difficult to the previous one (F3), and has the following characteristics: a) First, supportive learning material is presented to students before showing the problem to be solved (F6); b) a problem that has to be solved (F4); c) a set of puzzle pieces provided to the players to solve the problem; d) a feedback showing whether the solution proposed is correct or not (F5); e) a debriefing with the main conclusions in regards with the learning outcomes achieved in the level; and f) different hint mechanisms to assist players in reaching a correct solution (F7).

In concrete, the three mini-games support learning in the areas of computer architecture, programming fundamentals and computing networks concepts with the aim to be tested in regular secondary classroom sessions. The computer architecture game (see Figure 1, a) is focused on learning the main elements of the motherboard and the main elements of Boolean logic. Logic gates and elements of computer architecture are the pieces designed to provide a solution to the different levels. The programming fundamentals game (see Figure 1, b) is focused on learning three different algorithms structures (one per level): sequential, selective and iterative. Here, the pieces are related to different chunks of code such as, types of variables, numbers, operators, comparators or conditions. The game consists in providing the player with a skeleton of the code where should place the different pieces. Pieces have assigned different colors depending on the category they belong (i.e. variables, types, I/O sentences, operators and numbers). The computing networks game (see Figure 1, c) encourages players to solve three different situations (one per level): how to connect different elements to have ADSL in home, how the information travels through the network, and how information is sent from a personal computer to another. Routers, IPs, Computer ports, browsers or frames are examples of puzzle pieces in the game.

Figure 1. Some screenshots of the three games.
In order to gain more insights in the design of the games, some design variations were implemented in each game in regards with the immediate feedback or score (F5), supportive learning material (F6), and hints approaches (F7). First, we implemented different score mechanisms within the games. In many games, points can be useful at measuring the player’s success and be considered a gateway to reward players’ actions, but to the best of our knowledge there are no tips about how score should be designed for educational games. For this reason, we followed two different approaches regarding the score. The computer architecture game and programming fundamentals game start with an initial score (1000 points) and each time a player makes a wrong decision we decrease the punctuation of the score (see Figure 2, a). On the other hand, the computing networks game start with no score and increments the punctuation when players make correct actions and decrements when making mistakes (see Figure 2, b).

Second, we designed different hint approaches. The computer architecture game provides textual hinting (see Figure 3, a): each time a player places a piece in a specific position, a textual hint provides the player with some clues concerning whether a piece is in the right position or not. The programming fundamental game uses visual colour-coded hints (see Figure 3, b) concerning with showing the colour of the correct category of pieces. Then, the player knows that one of the pieces concerning to the specific category should be placed in that position. The computing network only provides textual descriptions for each piece describing the behaviour of the piece itself (see Figure 3, c).

IV. EVALUATING THE DIFFERENT MINI-GAMES

With the aim of evaluating the different games, we carried out several experiments in different high schools in Barcelona (Spain) with a total of 83 secondary students without previous knowledge in these subject matters. In particular: a) the computer architecture game was tested with 44 secondary students; b) we tested the programming fundamentals game with 20 high students; and c) 19 secondary students played with the computing networks game.

The main questions of interest for this study were: How do students perceive the 1) hints mechanisms?, 2) the score approach?, and 3) the supportive learning material?

The workflow in each experiment was the same:
- First, a brief explanation was given about the context in which the study is framed.
- Then, we split the students into two equal groups (one was using the game with hints and the other using the game without this assistance) and they individually played the game.
- Finally, the participants filled a simple questionnaire to evaluate the activity. The questionnaire was focused on: whether participants felt to have learned new concepts, the way participants reach a solution as well as the difficulties to reach the correct solution, and the positive and negative aspects of the game highlighting, among other things, the design of the score and the supportive learning material.

Table 1 summarizes the results related to each question of interest taking into account the participants’ answers provided in the questionnaire filled after playing the game.

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<th>Questions</th>
<th>Results</th>
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<td>How do students perceive the hints mechanisms?</td>
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<td>- 95% (in computer architecture game), 90% (in programming fundamentals game) and 90% (in computing network game) considered the assistance useful and enough to reach a solution</td>
<td>- 68% (in computer architecture game), 60% (in programming fundamentals game), and 77% (in computing network game) claimed for some kind of assistance</td>
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<td>- 26% reached the solution by trial and</td>
<td>- 45% reached the solution by trial and</td>
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When asking students about whether they had the perception of learning new concepts, we did not obtain significant differences from students who used the games with hints in relation with those who used the games without hints. In fact, 76% of participants using the games with hints believe they learnt new concepts over the 78% of participants that used the games without hints.

Regarding how participants achieved the right solution, 45% of those who used the games without hints reached the solutions by trial and error over the 55% who previously reflected on their decisions. We noticed more differences between participants using the games with hints. 74% of these participants admitted to reflect on their decisions opposed to 26% who admitted to reach the solution by trial and error. Besides, overall participants found the different levels of the games difficult to solve mostly because students did not have any previous knowledge in these topics. Besides, players find the game very difficult at the beginning since this topic was new for them. As stated in one of the questionnaires "at the beginning it [the game] is a bit complicated but it becomes more enjoyable while advancing forward" or for example in other questionnaire "At first I hesitated, but when I understood the dynamics of the game then it was easier".

Regarding the use of hints, 95% participants who used the computer architecture game with hints believed that the textual help was useful. In fact, 72% of these participants indicated they would not add any type of guidance; for example, some questionnaires indicated, "[hints] were nice" or "I think the game provided sufficient hints. Otherwise we wouldn’t learn anything". Moreover 68% of students that had used the version without hints claimed for some kind of assistance during the game progress. However, 32% of these participants did not agree on having hints since some of them thought, "with hints you don’t really think and learn" or "[hints] are not needed because the challenge is part of the excitement: More challenging, more emotion". Overall participants using the computer architecture game highlighted the need of hints indicating those pieces that are in wrong places or clues for different possibilities. Regarding the programming fundamentals game, 90% of participants using the version of the game with hints considered the assistance enough to reach a solution. On the other hand, 60% of participants who have used the version without hints would appreciate some sort of hints integrated in the game, for example, "a guide" or "further explanations". Most participants using the computing network game with scaffolding (9 of the 10) argued that the assistance provided was helpful. Students felt that the hints were enough. However, in some cases the participants would have wanted some extra guidance, for example, having "a wild card that would serve to guide more". Besides, 7 out of the 9 participants using the version without hints felt that they would need some type of assistance. Several suggestions were about providing more "learning supportive material" or "indicating what the wrong pieces are".

Last question was related to positives and negatives aspects of the different games. Overall, participants appreciated the design and graphics of the game. They had also found the game entertaining and though it was a good way to learn new concepts in a different and entertaining way, as well as the good structure of the game. On the other hand, the negative aspects were related to the difficulty of the game. Also, participants believed that in some cases the amount of information offered by the supportive learning material was excessive. Another aspect that most of the participants highlighted was related to starting the game with a high score and the fact this score only took into account the mistakes and did not reward the correct answers (in the case of computer architecture and programming fundamentals game). Besides, most of the participants who used the version of the games without hints stressed that at the beginning they did not know how to solve the different problems due to a lack of help.

V. DESIGN GUIDELINES FROM THE DIFFERENT EXPERIMENTS

From the data analysis we observed that hints were found necessary and helped participants to reach the correct solution. Moreover, most participants using the version without hints would find helpful to have some type of guidance. Besides, participants without hints reflect less than students with hints. This could be attributed to the fact that since participants did not have any type of guidance, they could have tried different possible combinations until reaching a solution.

The difficulty of the game was a negative aspect that the participants have commented, as well as, the amount of information provided by the supportive learning material. In this regard, it could be recommended that games must be designed by the teachers to correctly design levels according the students skills and to provide appropriate learning supportive materials.

Some few comments were also related to the score of the games. Mainly, participants highlighted the fact that the initial score provided by the game was too high and the fact of subtracting points when making mistakes and do not rewarding correct answers.

Taking into consideration the results obtained from the different experiments we expose some considerations in regards with the design of hints (question 1), score (question 2) and learning supportive material (question 3) for designing puzzle-based mini-games:

- Hints should guide players along the different stages of the game. It is important to notice that hints should be optional: players can use hints to advance forward the game and keep motivated in order to avoid frustrations, or player may choose not to use hint since they can find more challenging to arise the solution without any kind
of guidance. But, whatever the design of the hint (e.g. textual or visual) it is important to specify the pieces that are placed in wrong positions and indicate possible candidates.

- Regarding the score of the game, it is important to consider two aspects. On the one hand, a key point consists in avoiding starting the game with a higher punctuation. It is better to start with no points to provoke the player a sense of overcoming and promote achieving higher scores in order to become better than providing a higher score that can discourage players. On the other hand, taking this aspect in consideration, it is important that correct decisions on players’ actions add points to the scores instead of taking only in consideration wrong answers. This would avoid having frustrations among players since they appreciate their correct decisions instead of focusing only on their mistakes.

- Supportive learning material should not be considered in the game as a standalone resource. In fact, when this happens players are bored and find theory too heavy. In that sense, theory should be integrated in the storytelling of the game and also it should be necessary to find innovative ways to embed theory along the narrative of the game in such a way that players learn the theoretical concepts in a more pleasant and funny way.

VI. CONCLUSIONS

Hints (question 1) integrated in these games have been useful to reach the correct solution. In addition, participants using the games with hints reflected more when proposing a solution than those who used the version without hints. This could be attributed to the fact hints can encourage players to think of the correct solution and when participants do not have any type of guidance, they tend to try different possible combinations until reaching a solution. Besides, participants suggested some improvements, such as indicating the wrong parts of a proposed solution or providing hints showing possible candidates to a concrete solution. Further research lines emerge in regards with designing appropriate hints approaches depending on the context of the game.

When designing supportive learning material (question 2), further research is still needed to address the amount of information provided to the players as well as the way the information should be presented or integrated within the game. In this regard, teachers play an important role in correctly designing appropriate learning supportive materials.

Regarding the score (question 3), we followed two different approaches: a) starting with an initial score and decreasing it each time a player makes a mistake (computer architecture and programming fundamental games), and b) starting with no score and increasing points for correct answers and decreasing points for incorrect answers (computing network game). While participants did not comment anything in regards with the second approach, the first one, received negative comments. Participants become frustrated because the game only took in consideration mistakes and did not reward good decisions. In that sense, further research has to do with how to properly design the punctuation mechanisms.

In conclusion, this paper has presented three mini-games within the areas of computer architecture, programming fundamentals and computing networks. These games are characterized by puzzle solving the different levels of the games with the help of textual and visual hints. From an evaluation with secondary students we describe several considerations for the design of this type of games in regards with hints, score and learning supportive material.

ACKNOWLEDGMENTS

This research has been partially funded by the Spanish Ministry of Science and Innovation in the Learn3 project (TIN2008-05163/TSI) and the EEE Project (TIN2011-28308-C03-03). The authors would also like to thank Tomás Bueno, Ruben Cobo and Sergio Turull.

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